Optical Communication Demonstration and High-Rate Link Facility

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Abstract. Motivated by demands for faster, better, cheaper spacecraft, NASA is developing deep-space optical communication technology which promises reduced mass, volume, and power consumption compared to radio-frequency technology. While earth-orbiting optical receivers may eventually be employed, initial deep-space optical communication links are expected to utilize terrestrial telescope receivers. As the communication beam passes through the atmosphere, atmospheric turbulence causes the beam to scintillate, dramatically impacting its temporal and transverse nature. The statistics of these effects must be measured extensively if optical deep-space communication links are to be fully modeled and the design of deep-space communication links optimized. Sponsored by the Engineering Research and Technology Development program, the purposes of the Optical Communication Demonstration and High-Rate Link Facility are to demonstrate a Gbps-class optical downlink, gather extensive link statistics, and provide high-rate downlink capability. The Optical Communication Demonstration and High-Rate Link Facility will be deployed to the International Space Station by flight UF-4, currently scheduled for May 2002.

INTRODUCTION

Optical communication is renowned for the dramatic success of the fiber-optic network which largely has replaced electrically conductive communication methods in long-haul applications. Whereas fiber-optic communication systems employ optical waveguides to transfer optical pulses from sender to receiver, free-space optical communication systems employ no transmission medium, propagating optical pulses from sender to receiver solely through the atmosphere or the vacuum of space. The National Aeronautics and Space Administration (NASA) through the Jet Propulsion Laboratory (JPL) is developing optical communication for deep-space applications as a method to achieve NASA's goal of smaller, lighter, less expensive spacecraft possessing increased communications rates. Optical communication technology reduces mass, power consumption, and volume compared to radio-frequency technology[1]. At the same time, the demand for information transfer capacity, the high bandwidth available in optical communication, and the scarcity of available radio-frequency bandwidth have combined to prompt future satellite networks such as Teledesic to baseline optical communication for intersatellite links.

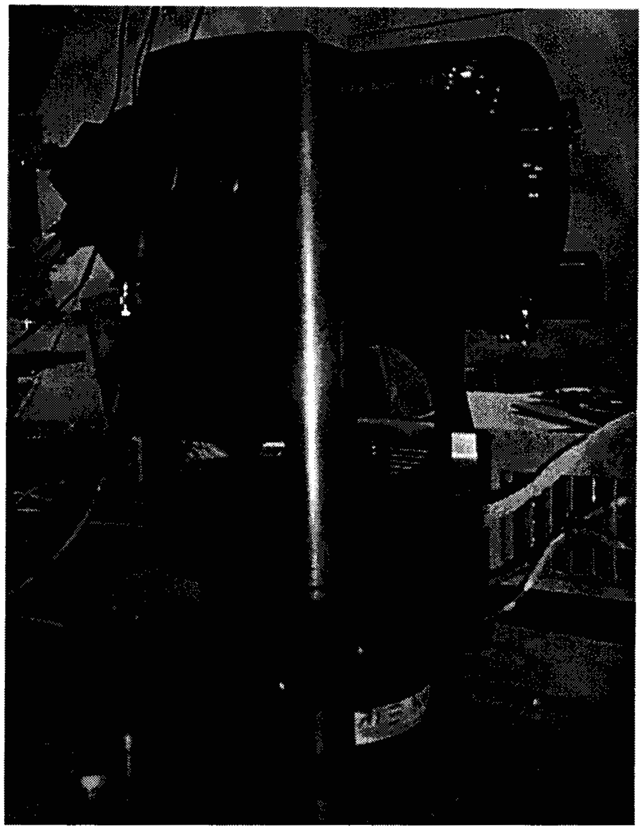

FIGURE 1: The Optical Communication Demonstrator (OCD), a laboratory-qualified optical communications terminal.

As part NASA's technology development, the Jet Propulsion Laboratory has designed and built a laboratory-model optical communications terminal called the Optical Communications Demonstrator (OCD)[2,3]. A photograph of the OCD is shown in Figure 1. Following up on successful laboratory work, the OCD recently completed a ground-to-ground optical communication link demonstration between two mountains separated by more than 40 km. This propagation path possesses much harsher atmospheric turbulence properties than are expected in earth-orbital-to-ground links, and provides a useful worst-case demonstration of the basic capability of the technology. In this paper we focus on plans for an optical communication demonstration from the International Space Station (ISS) to ground. This demonstration will investigate the performance of an OCD-type optical communications terminal in a space environment and the impact of atmospheric effects on the communication link.

DEMONSTRATION OBJECTIVES

The objectives of the demonstration are to establish a Gbps-class link from the International Space Station to ground, collect extensive link statistics, measure the performance of the flight unit, and provide a high-rate downlink capability to neighboring ISS external payloads. The performance of the flight unit will be characterized by several parameters including the amount of time required to acquire and lock onto the beacon beam and its ability to maintain track of that beacon beam in the presence of ISS platform vibrations and atmospheric scintillation of the laser beacon. The flight unit will include both an on-board accelerometer package to determine whether or not the flight terminal is being subjected to vibrations which its tracking control loop cannot compensate and a beacon laser scintillation monitor to collect statistics of the atmospheric turbulence-induced intensity fluctuations of the beacon beam. Correlating platform vibration information with the frequency of lost tracks will result in an improved understanding of the flight unit's control loop performance. Data from the scintillation detector, which employs a

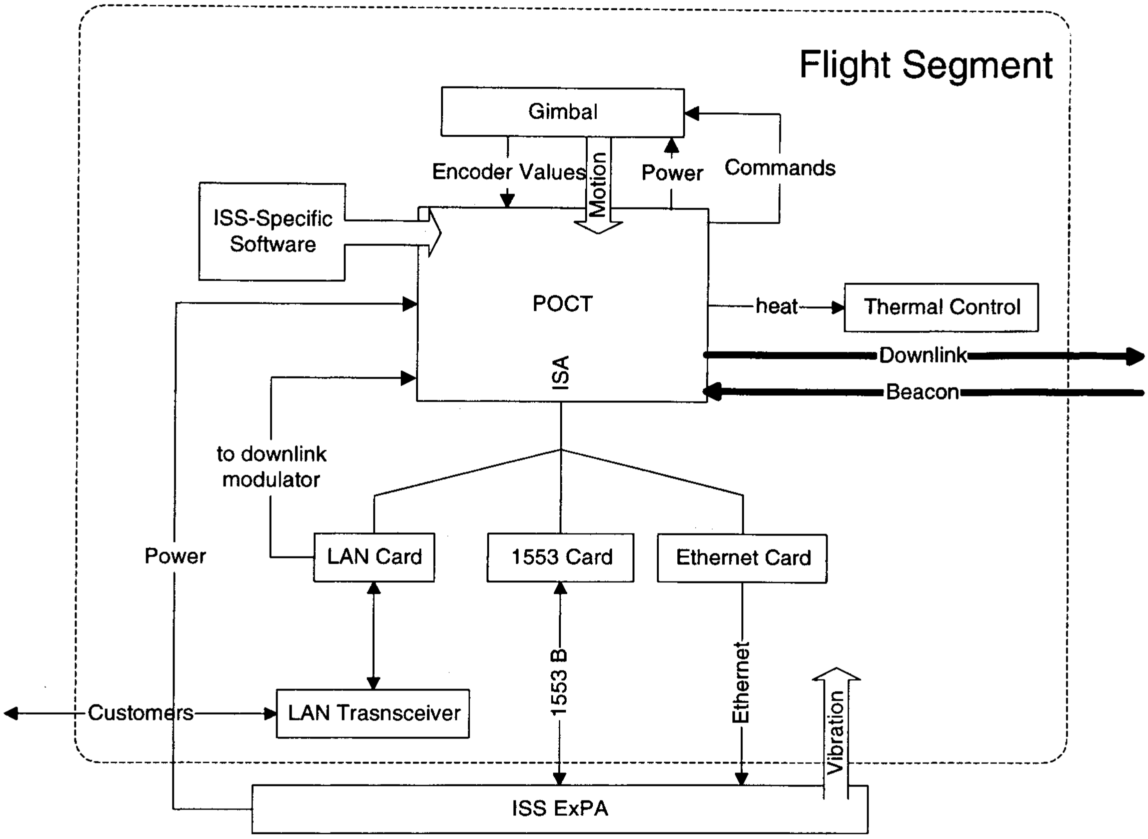

FIGURE 2. The flight hardware includes the protoflight optical communication terminal (POCT), a gimbal for rough pointing, and electronic interfaces including the 1553 B command and control system and an Ethernet connection. A local-area network (LAN)-type connection may be used to provide an interface to customers.

wideband photodetector followed by a low pass filter and an analog-to-digital converter, will be analyzed and compared with theories of the impact of atmospheric turbulence on optical beams.

A statistically meaningful measurement of these observables requires a large number of downlink transmissions, and measurement of seasonal changes in statistical distributions requires at least one year's flight. The International Space Station (ISS) provides such a long-duration flight opportunity and its planned orbit creates on the average two link opportunities per day. If one-third of the opportunities are clouded out, around 240 link opportunities are expected, providing a sufficient sampling of the statistical properties of scintillation as a function of parameters such as solar angle, zenith angle, weather conditions, and seasonal changes.

THE FLIGHT TERMINAL

Figure 2 is a block diagram of the flight hardware, the core of which is the Protoflight Optical Communications Terminal (POCT). The POCT is essentially the proven OCD architecture enhanced by modern performance-improving components including a JPL active pixel sensor (APS) and a commercial high-speed fine-steering mirror (FSM). In addition to simply demonstrating the optical communication link, the performance of these APS and FSM technologies baselined for NASA deep-space optical communication terminals will be measured in a space environment. The block diagram also shows the gimbal which provides rough pointing of the POCT optical axis.

The POCT contains the optics, electronics, software, and laser fundamental to establishing the optical communication link. The POCT laser transmitter design incorporates a high-speed single-mode semiconductor distributed feedback (DFB) laser followed by a fiber amplifier. An integrated isolator module minimizes the effect of feedback signals. The DFB laser and amplifier combination possesses the modulation bandwidth and output power necessary to establish the Gbps-class optical link. The laser transmitter design also includes an internal PIN photodetector to monitor optical power and a TEC cooler to stabilize operation over the temperature range. Data input from the customer channel is accepted at ECL levels in a non-return to zero (NRZ) format.

INTERFACE TO THE INTERNATIONAL SPACE STATION

The POCT interfaces mechanically, electrically, and electronically to an International Space Station EXpedite the PRocessing of Experiments to the Space Station (EXPRESS) Pallet Adapter (ExPA). The ExPA is essentially a bolt-hole grid with standard electrical and data connectors, and six ExPAs are attached to each EXPRESS Pallet. The EXPRESS Pallets attach to the S3 truss site as shown in Figure 3. The flight terminal utilizes one of the nadir-looking EXPRESS Pallets. The electronic interfaces to the ExPA shown in Figure 4 include the 1553 B command and control system , the ExPA Ethernet connection.

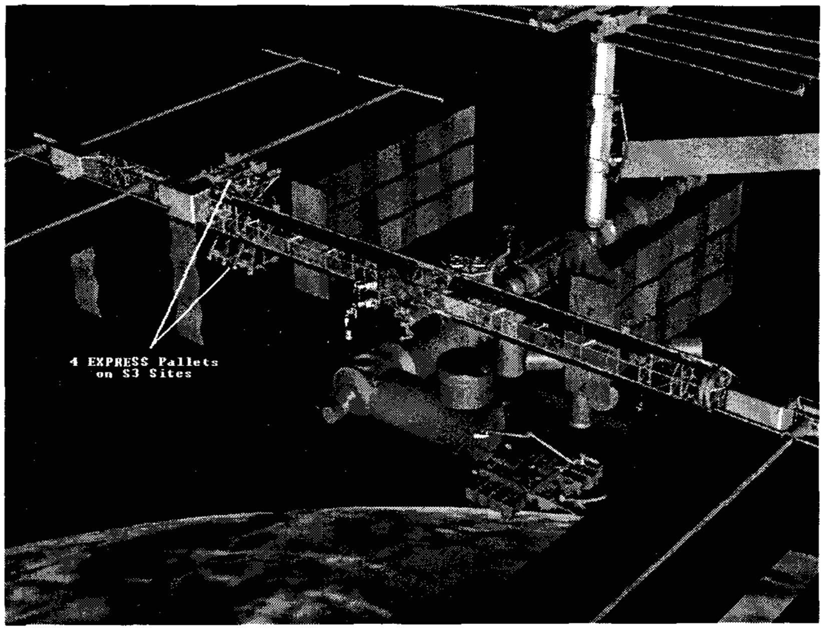

FIGURE 3. The International Space Station. Four sites are provided along the starboard truss for the attachment of EXPRESS Pallets.

POCT accepts commands, ancillary data, and standard time data from the EXPRESS Pallet Controller (ExPC) via a MIL-STD-1553 interface. Its control software will accommodate receiving commands and broadcast ancillary data at 10 Hz, time broadcast at 1 Hz, and additional ancillary data at 0.1 Hz. In addition, the flight software will provide health and status data to the ExPC via the MIL-STD-1553 interface and will transfer science and systems data to the ExPC via the IEEE 802.3 Ethernet 10 Base-T interface.

GROUND STATION

The ground terminal for the demonstration will be the Optical Communication Telescope Laboratory[4] (OCTL) slated to be built at the Jet Propulsion Laboratory's Table Mountain Facility near Wrightwood, CA. The heart of the OCTL is an altitude / azimuth -mounted telescope with a primary mirror nominally 1 meter in diameter. The OCTL both receives the optical downlink from the flight terminal and provides the laser beacon which illuminates the flight

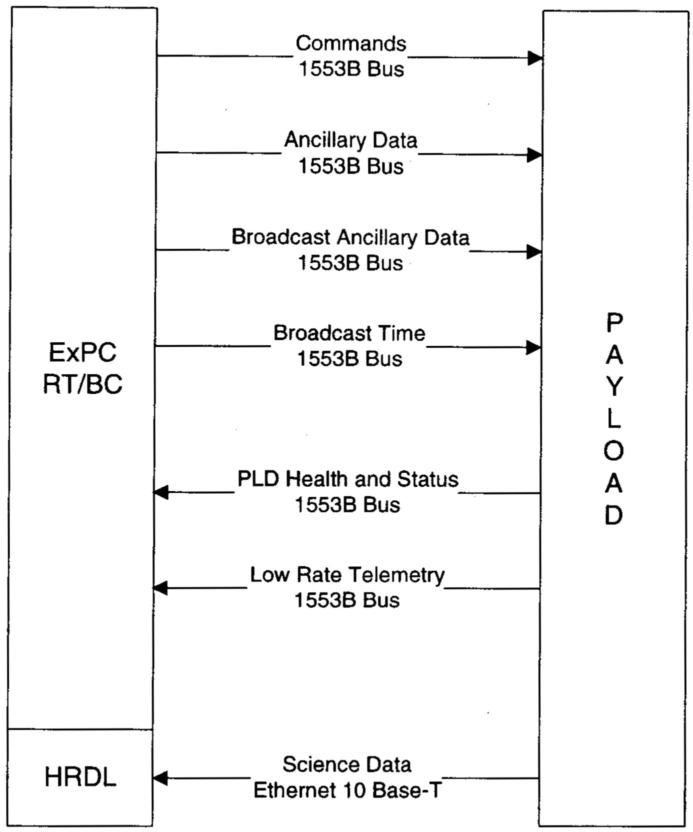

FIGURE 4. The data interfaces between the payload and the EXPRESS Pallet Controller (ExPC). The EXPRESS Pallet Controller interfaces the EXPRESS Pallet to the International Space Station electrical and data systems and regulates data and electrical services to the payloads. The ExPC is the bus controller for the 1553B command and control data bus.

terminal. To mitigate the effects of atmospheric scintillation on the laser beacon, multiple laser beams will be transmitted to the flight terminal. The incoherent averaging of these multiple beams reduces the scintillation seen by the flight terminal, as was illustrated in the Ground-to-Orbit Lasercomm Demonstration[5]. The ground station includes a commercial off-the-shelf data recovery unit which performs signal detection, clock recovery, and data retiming.

SUMMARY

In summary, the Jet Propulsion Laboratory will deploy to the International Space Station in May 2002 a Gbps-class optical communications transmitter which employs components of the NASA deep-space optical communication technology set. The demonstration will measure the performance of these components and of the flight terminal in general as well as the statistics of the communications link. Such measurements require the large number of link opportunities and the long-duration flight provided by International Space Station.

ACKNOWLEDGMENT

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